Image-dependent Gamut Compression and Extension

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Abstract

Gamut mapping from displayed image onto print is a current topic in cross-media color reproduction Current gamut mapping algorithm (GMA) is mostly addressed to compress the out-of-gamut colors into the inside of printer gamut. Indeed, the highly saturated CG images or electronic paintings on monitor should be compressed to make the appearance matching to print. However, the printer gamut has been much expanded with the improvements in printing media. Hence, source image doesn't always fulfill the entire device gamut, and sometimes its gamut had better to be extended for the better color renditions.

Current GMAs are designed to work in 2-D lightness-chroma planes based on device-to-device (D-D) gamut relations not on image-to-device (I-D). Of course, I-D GMA is preferable than D-D and is desirable to map the colors directly and seamlessly in 3-D color space. Our approach is based on I-D and directed toward seamless real 3-D mapping. This paper proposes an advanced GMA coupling the two types of mappings, one for compression and the other for extension. The mapping results narrow from/to wide gamut are reported.

Introduction

To print the CRT image, GMA should be designed considering the three different gamut boundaries, that is, ***monitor***, ***printer***, and ***image***. The proposed system selects the compression GMA or extension GMA whether the image gamut is obviously larger or extremely smaller than printer gamut. Fig.1 shows how a CG image gamut is larger and a natural scene gamut is smaller than the inkjet printer gamut. Fig.2 illustrates the process diagram of the proposed GMA. In the compression GMA, the source colors are mapped into the inside of printer gamut based on the image-to-device 3D gamut boundary relations. Here it will be a serious task to extract the image gamut surface and to find the intersection points on the surface. While in the extension GMA, the image gamut is stretched to the Gaussian distribution function as a target in lightness and chroma histograms.

The extension GMA is aimed to preferred color reproduction.

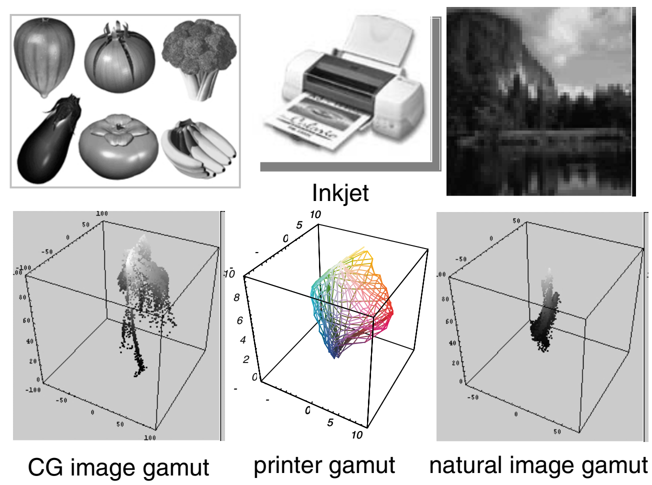

Figure 1. Two types of image vs. device gamut relations

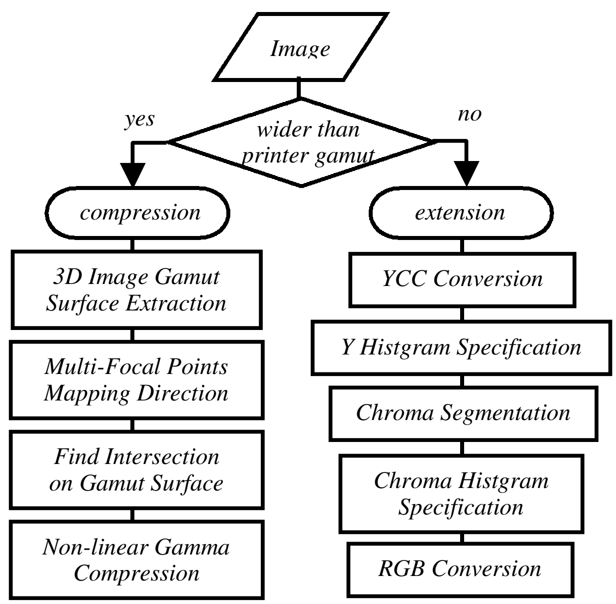

Figure 2. Diagram of proposed gamut mapping system

3D Gamut Compression

Image-to-Device Mapping

In the current 2D ***D-D*** GMA, the source color ***s*** is mapped to the destination ***t*** in relation to the monitor gamut boundary ***m*** vs. printer's boundary ***o*** toward a focal point ***p***. However, the saturation and gradation losses will happen after the mapping, because the image color distributions don't always fill the entire monitor gamut. While, the ***I-D*** GMA[1] uses the image gamut boundary ***i*** instead of ***m***, then it can suppress such losses in minimum (See Fig.3).

Since the 2D mapping is done in a hue segmented Lightness-Chroma (L-C) plane, the unwanted artifacts often appear when passing across the one hue leaf to another. Here we extended the 2D I-D into seamless 3D I-D GMA[2].

The key points to success in 3D GMA are

- ***Extraction of 3D image Gamut Surface & Description***
- ***Use of Non-linear Mapping Function***
- ***Mapping into Multi-Focal Points depending on Lightness distribution***

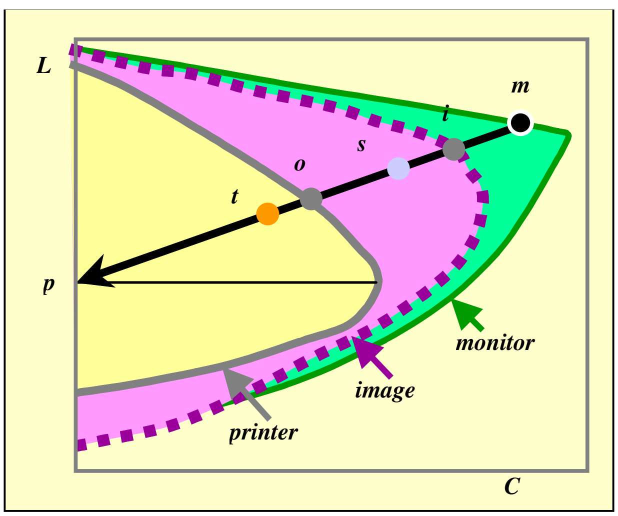

*Figure 3. Basic Concept of **I-D** (Image-to-Device) GMA in 2D*

Extraction of 3D Image Gamut Surface

We have developed an automatic gamut surface extract-ion algorithm[3] from a random color distribution as shown in Fig. 4. Here the most outside color points on gamut surface are extracted from the following segmentation steps.

(1) First, the segmentation number R_t is decided by the cube root of pixel number N, where INT means the integer.

$$Rt = INT(\sqrt[3]{N}) \tag{1}$$

(2) An image color center $(L^*,a^*,b^*)_{avg}$ is computed by

$$(L^*,a^*,b^*)_{avg} = \frac{1}{N}\sum_{i=1}^{n}(L^*_i, a^*_i, b^*_i) \tag{2}$$

(3) The whole color space is segmented into R_t sectors $\times$ R_t segments divided by hue angle θ and sector angle ϕ measured to the image center.

An example of 3D image gamut surface is shown in Fig. 5 represented by polygon meshes from the surface points.

$$\theta = \tan^{-1}\left(\frac{b^* - b^*_{avg}}{a^* - a^*_{avg}}\right) \tag{3}$$

$$\phi = \tan^{-1}\left(\frac{L^* - L^*_{avg}}{\left[(a^* - a^*_{avg})^2 + (b^* - b^*_{avg})^2\right]^{1/2}}\right) \tag{4}$$

Where, the pixels are non-uniformly divided by $(\Delta\theta_i, \Delta\phi_j)$ to include the constant sample number R_t in each ij sector for $i=1\sim R_t$ and $j=1\sim R_t$ (See Fig.4).

(5) Finally, the farthermost pixel from the image center is selected as surface point in each sector.

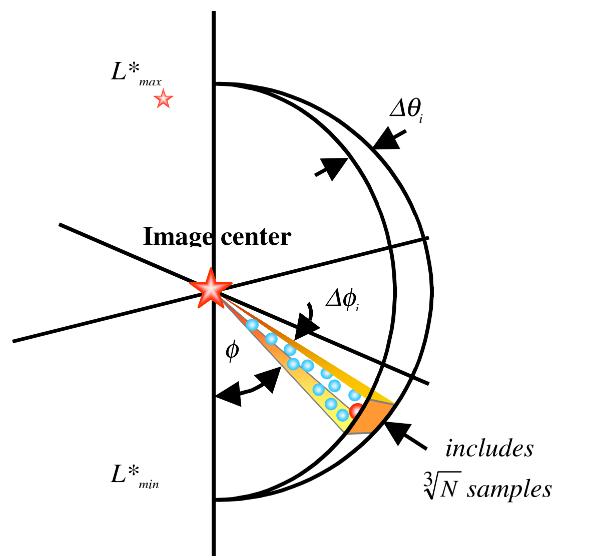

Figure 4. 3D Gamut surface extraction method by $\sqrt[3]{N}$ division rule

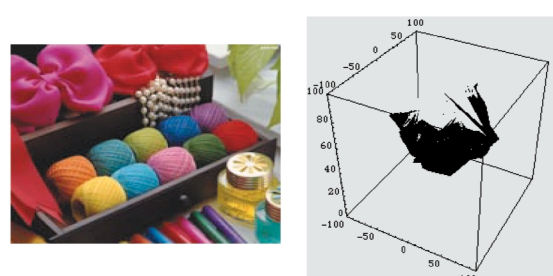

Figure 5. Gamut surface of "wool"

Nonlinear Gamma Compression Function

In 3D CIELAB space, a source color ***s*** is mapped to target ***t*** along the mapping line toward focal point ***p*** referenc-ing to the image gamut boundary ***i*** and output device gamut boundary ***o*** as given by the following vector notations.

$$\overrightarrow{pt} = \overrightarrow{po}\cdot\left(\frac{\overrightarrow{ps}}{\overrightarrow{pi}}\right)^{\gamma} \tag{5}$$

Hερε, γ represents the gamma-compression coefficient.

The GMA works as linear compression for $\gamma=1$, and as nonlinear compression for $0<\gamma<1$.

Mapping towards Multi-Focal Points

The mapping into a single focal point used in the typical 2D GMA, lowers the lightness reappearance fatal to the image quality. To keep the natural lightness, a mapping into the multi-focal points is desirable. We developed a decision method for multi-focal points named ***ILD*** (***Image Lightness Division***). ***ILD*** method divides the lightness histogram into ***n*** intervals for each to include the constant *k* samples. To hold the lightness balance after mapping, ***n*** focal points $\{\boldsymbol{p}_i\}$; $i=1\sim n$ are set on the lightness gravity in each L^* interval. The gravity $\boldsymbol{p}_i$ is calculated as follows (Fig.6).

$$P_i = \left(\sum_{j=1}^{k} L_{ij} f_{ij}\right)\left(\sum_{j=1}^{k} L_{ij}\right)^{-1},\ i = 1 \sim n \tag{6}$$

Where L_{ij} represents the *j-th* lightness value in the *i-th* interval, and f_{ij} represents the occurrence frequency of lightness L_{ij}.

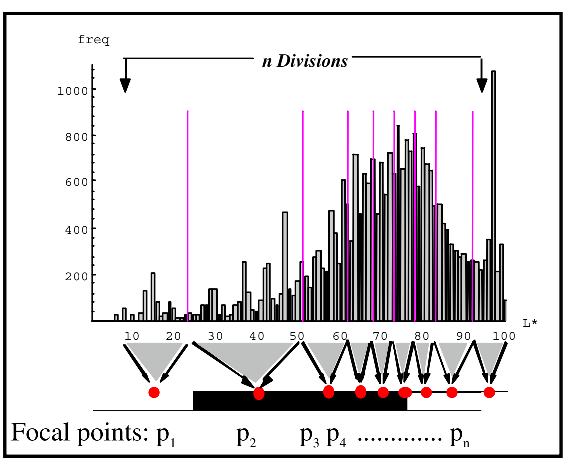

*Figure 6. Decision of multi-focal points by **ILD** method*

3D Gamut Compression Result

A CG image sample by 3D I-D GMA is shown in Fig. 7. As compared with typical 2D clipping GMA, 3D GMA gives a seamless mapping without segmentations, then without causing any artifacts such as discontinuities in tonal gradation and hue changes as observed in persimmon. In our psychophysical opinion test, the proposed 3D I-D GMA using multi-focal points ILD resulted in the best z-score in comparison with other 2D D-D GMAs or 3D I-D GMA with single focal point. Fig. 7 shows an example by 3D GMA.

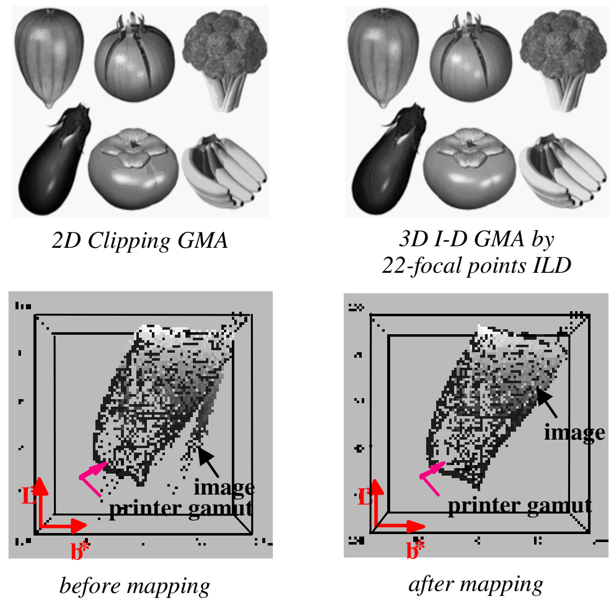

Figure 7. Result by 3D I-D GMA

Gamut Extension for De-saturated Image

Objectives of Image Gamut Extension

The major objective of gamut extension is to recover the degraded colors taken under insufficient illumination or faded colors after long preservation. It is difficult to restore the lost original colors exactly, but possible to recover the pleasant colors by gamut extension. Sometimes, the pictures even if taken by digital camera, only fill the narrow gamut ranges as compared with modern wide gamut media such as hi-fi inkjet print and hoped to be corrected to vivid colors.

Gamut Extension by Color Histogram Specification

We propose an image gamut extension method based on Histogram Specification (HS). To simplify the process, the histograms of luminance and chrominance are extended separately in YCC space as the following steps.

(1) RGB to YCC conversion
(2) Gaussian HS for Y component
(3) Segmentation of chroma component
(4) Gaussian HS for chroma component

Gaussian Histogram Specification for Y image

Histogram Equalization (HE) method is useful to expand the reduced dynamic ranges of monochrome image. However, HE can't be applied to tri-color images, because it causes unnatural and unbalanced color appearance. There is no definitive solution to what shapes of the color histogram are comfortable. In our experiments, Gaussian histogram was an effective candidate to create the natural and pleasant images. First, the histogram of luminance Y is converted to the Gaussian distribution through HE as follows.

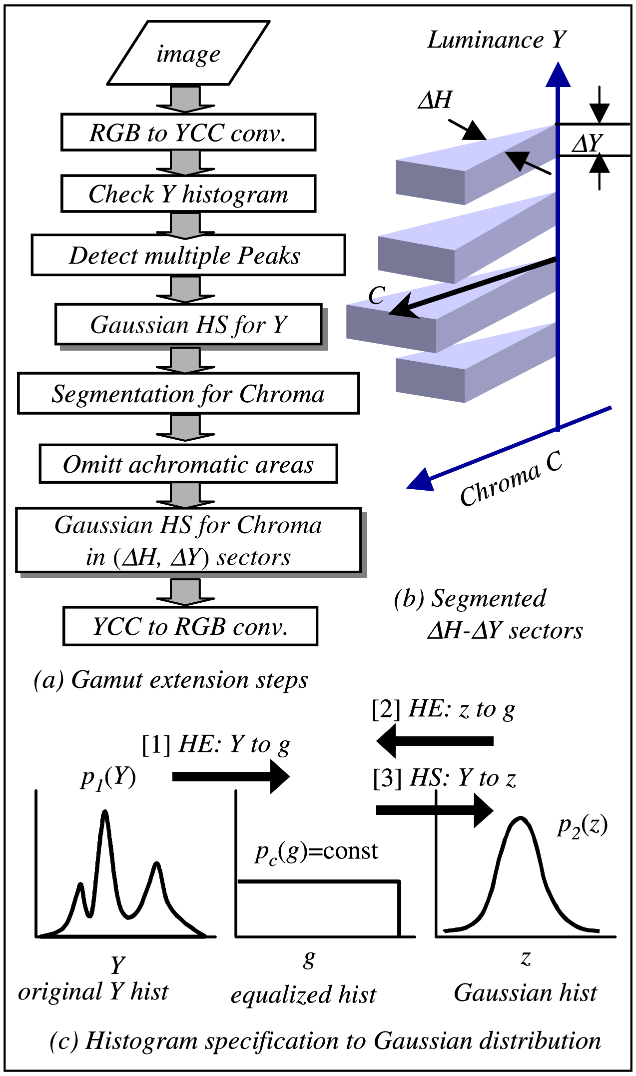

Figure 8. Improved image by gamut extension

The original luminance Y is transformed to g by HE and the histogram $p_1(Y)$ is flattened to constant $p_c(g)$ as

$$g = F(Y) = \int_0^Y p_1(x)dx, \quad p_c(g) = \text{constant} \qquad (7)$$

Where, $p_1(Y)$ denotes the probability density of value Y occurrence. Now, our target histogram $p_2(z)$ is Gaussian

$$p_2(z) = \frac{1}{\sqrt{2\pi}\sigma} \mathbf{exp}\left\{-\frac{1}{2\sigma^2}(z-\bar{z})^2\right\} \qquad (8)$$

and z is also equalized into constant $p(g)$ by HE as

$$g = G(z) = \int_0^z p_2(x)dx, \quad p_c(g) = \text{constant} \qquad (9)$$

Thus, connecting two g's after HE from Y to g and z to g, the objective transform from Y to z is given by the inverse

$$z = G^{-1}(g) = G^{-1}(F(Y)) \qquad (10)$$

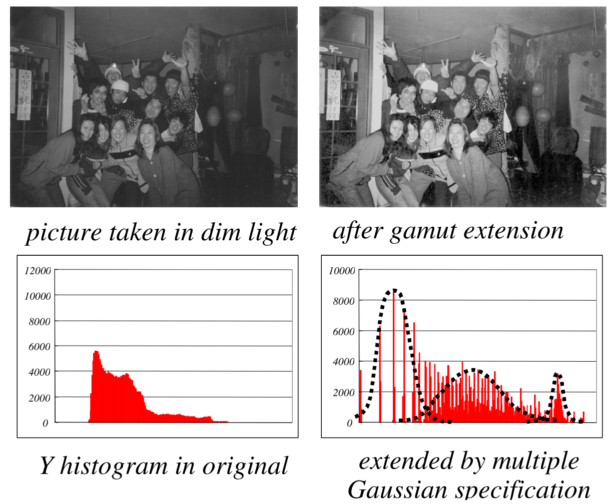

Figure 9. Gamut Extension Process by Color Histogram Specification

Gaussian Histogram Specification for Chroma Image

After the histogram specification of Y, the chrominance components are segmented into $n*m$ small sectors (n slices by ΔY in Y and m divisions by ΔH in hue angle H). Then chroma C of each sector is extended by Gaussian HS as same as Y without changing color hue. For example, whole pixels are segmented into totally $n*m = 10*16=160$ sectors and each was extended by individual Gaussian HS.

Considerations on Neutral Gray and Multiple Peaks

Furthermore, the achromatic areas were excluded beforehand from the process to avoid the unwanted coloring of grayish pixels. Sometimes, the Y histogram has not always a single peak but multiple peaks. For such cases, the histogram was specified to multiple Gaussian distribution functions centered at peak positions in original Y histogram. The color gamut extension process by HS is shown in Fig. 8.

Figure 9 shows an improved image by gamut extension using Gaussian histogram specification. The luminance Y histogram was specified to multiple Gaussian distribution functions and naturally stretched to wide range. The chroma was segmented to 16*10 ΔH-ΔY sectors and each sector was also extended by Gaussian HS algorithm. The picture taken in dim light was dramatically improved to comfortable image with the bright and vivid colors.

Conclusion

The paper proposed an approach to GMA from both sides of compression and extension. Two different GMAs were introduced, one for compression from wide to narrow and the other for extension from narrow to wide gamut. We could design the 3D compression GMA logically, but have no definitive design rule for the extension GMA at present. However both algorithms are based on the common concept of "***image-dependent***". Future works will be continued to find the better gamut extension algorithm based on this concept and on the human visual appearance tests.

References

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2. Chen H. S and H. Kotera, IS&T NIP16, pg.787 (2000).
3. R.Saito and H. Kotera, Proc. 8th. CIC, pg.330 (2000)

Biography

Hiroaki Kotera received his B.S degree from Nagoya Institute of Technology in 1963 and Doctorate from University of Tokyo in 1987. In 1963, he joined Matsushita Electric Industrial Co. Since 1973, he has been working in digital color image processing at Matsushita Research Institute Tokyo, Inc. In 1996, he moved to Chiba University. He is a professor at Dept of Information and Image Sciences. He received Johann Gutenberg prize from SID in 1995.